Advanced Neutron Absorbing Alloys

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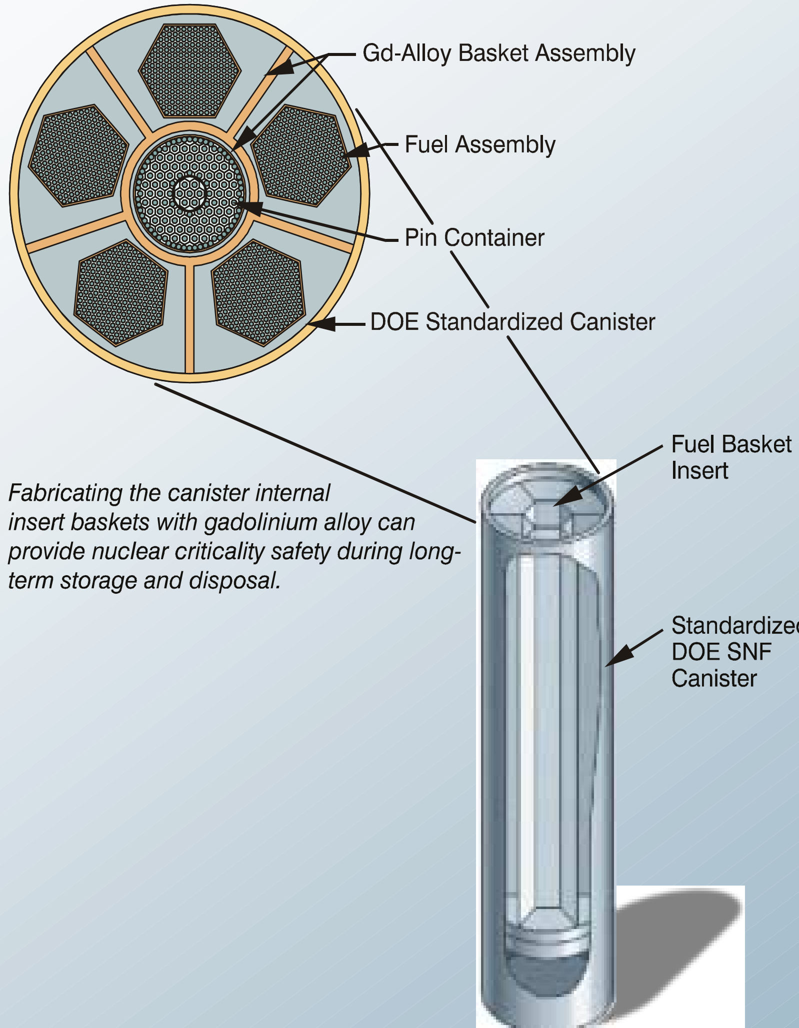
Overview

- The DOE fuel management approach is to package it in the standardized canister that will contain the SNF during interim storage, transportation, and long-term storage.
- The standardized canister will need neutron- absorbing structural inserts for criticality control.
- The technical objective is to develop weldable Ni-Cr-Mo structural alloys with gadolinium additions that have acceptable mechanical properties and corrosion resistance using conventional ingot metallurgy techniques
- The research team includes the INEEL, Sandia National Lab, and Lehigh University

Fast Flux Test Reactor Fuel Canister



Fabricating the canister internal insert baskets with gadolinium alloy can provide nuclear criticality safety during long-term storage and disposal.

01-GA50018-05

Development Program Progress (FY 00)

- The FY 00 program focused on Gd alloyed 316L stainless steel but hot workability problems were encountered
- Encouraging results were obtained with a Ni-Cr-Mo-Gd alloy at the end of FY 00
- The FY 01 program started with three compositions of Ni-Cr-Mo-Gd alloys and one composition of Ni-Cr-Gd alloy

Ni-Cr-Mo-Gd Program (FY 01)

- Evaluate Ni-Cr-Mo-Gd composition ranges to obtain optimum alloys for hot forming and welded structural applications
- Perform mechanical, physical, impact, and welding properties tests to generate a properties database for ASTM specification and ASME code application.
- Perform corrosion testing to measure localized corrosion resistance (gadolinium will not be removed from alloy matrix)
- The testing has focused on Test Composition “A”

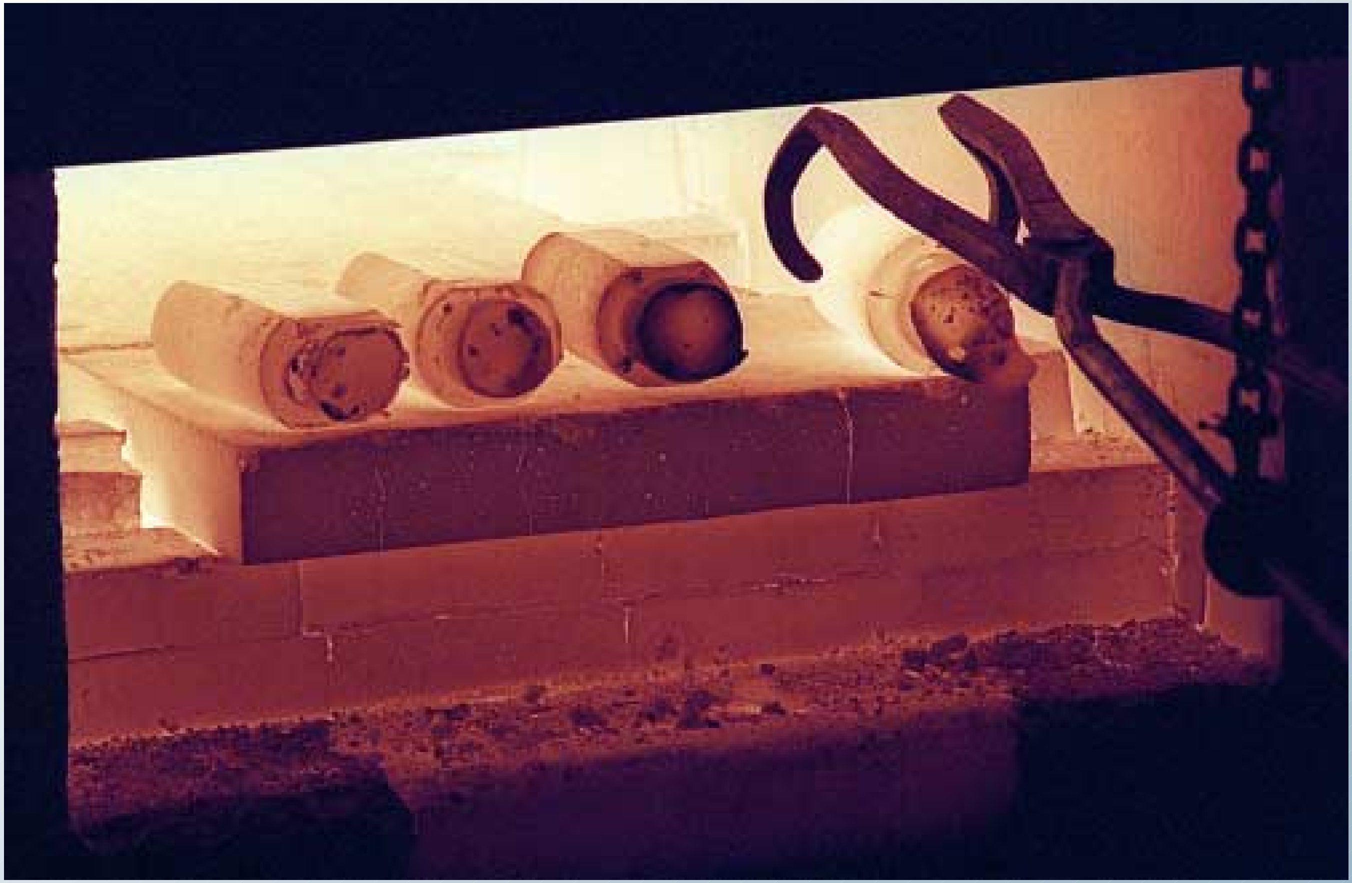
Alloy Design

- Four alloy compositions selected for study(UNS- N06455, N06022, N06059, Ni-Cr)
- Melt targets calculated from knowledge of gadolinide composition (essentially $(Ni,Cr)_5Gd$) to provide matrix with appropriate composition
- Principal adjustments are in Cr, Mo, and residual elements
- Alloys produced at Special Metals Corporation using conventional processing

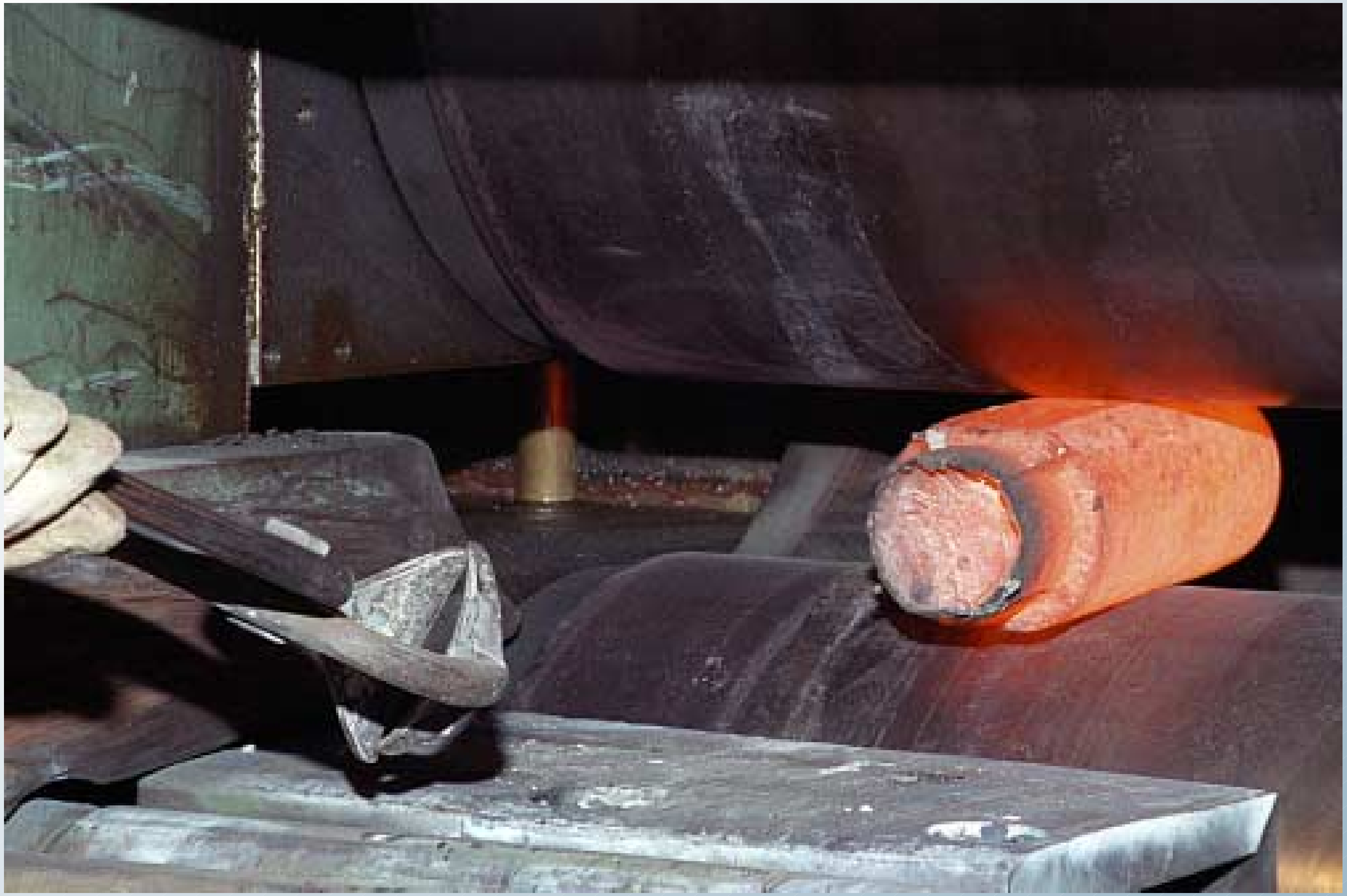
Element	NO6455	Target (Test Alloy A)
Mo	14.0-18.0	13.07-15.86 (14.93)
Cr	14.0-17.0	13.24-16.97 (15.11)
Fe	3 max	1.0 max
Co	2 max	0.3 max
C	0.01 max	0.010 max
Si	0.08 max	0.08 max
Mn	1.0 max	0.5 max
P	0.025 max	0.01 max
S	0.010 max	0.005 max
Ni	bal	bal
N	---	0.010 max
O	---	low as possible
Gd		2.2-2.5 (2.25)

Ni-Cr-Mo-Gd Chemistry Ranges

Element	Test Alloy A	Test Alloy B	Test Alloy C	Test Alloy D
Mo	13.07-15.86	11.67-13.53	14.00-15.39	– – –
Cr	13.24-16.97	18.83-21.5	20.69-22.55	20.54-22.38
Fe	1.0 max	1.92-3.78	1.0 max	1.0 max
W	– – –	2.33-3.26	– – –	– – –
Co	0.3 max	0.3 max	0.3 max	0.3 max
C	0.020 max	0.020 max	0.020 max	0.020 max
Si	0.08 max	0.08 max	0.08 max	0.08 max
Mn	0.5 max	0.5 max	0.5 max	0.5 max
P	0.01 max	0.01 max	0.01 max	0.01 max
S	0.005 max	0.005 max	0.005 max	0.005 max
Ti	– – –	– – –	– – –	– – –
Ni	bal	bal	bal	bal
Al	– – –	– – –	0.1-0.3	– – –
N	0.010 max	0.010 max	0.010 max	0.010 max
Gd	2.2-2.5	2.2-2.5	2.2-2.5	2.2-2.5

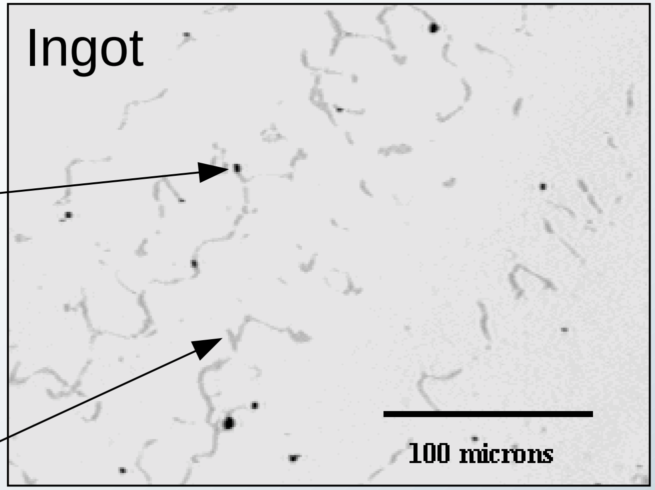


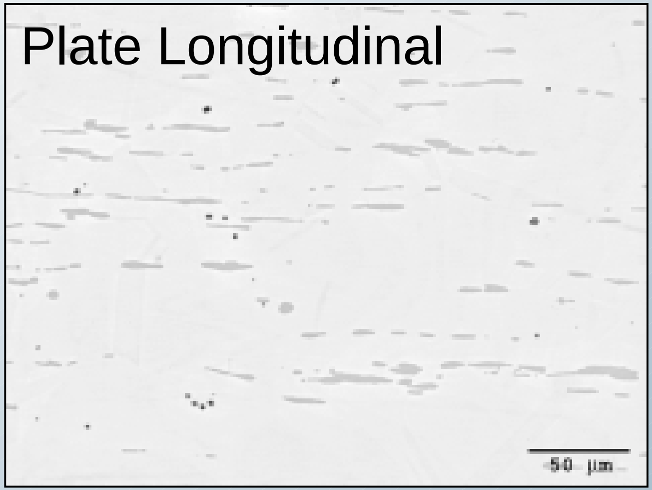
Ingot heating before rolling



Ingot Rolling

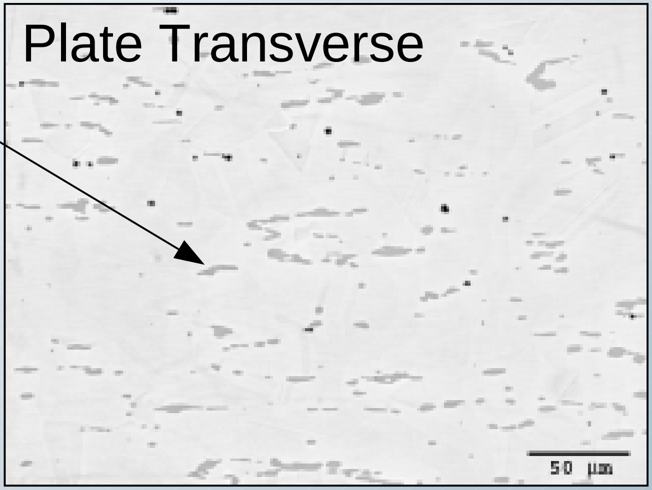
Ingot and Plate Microstructure



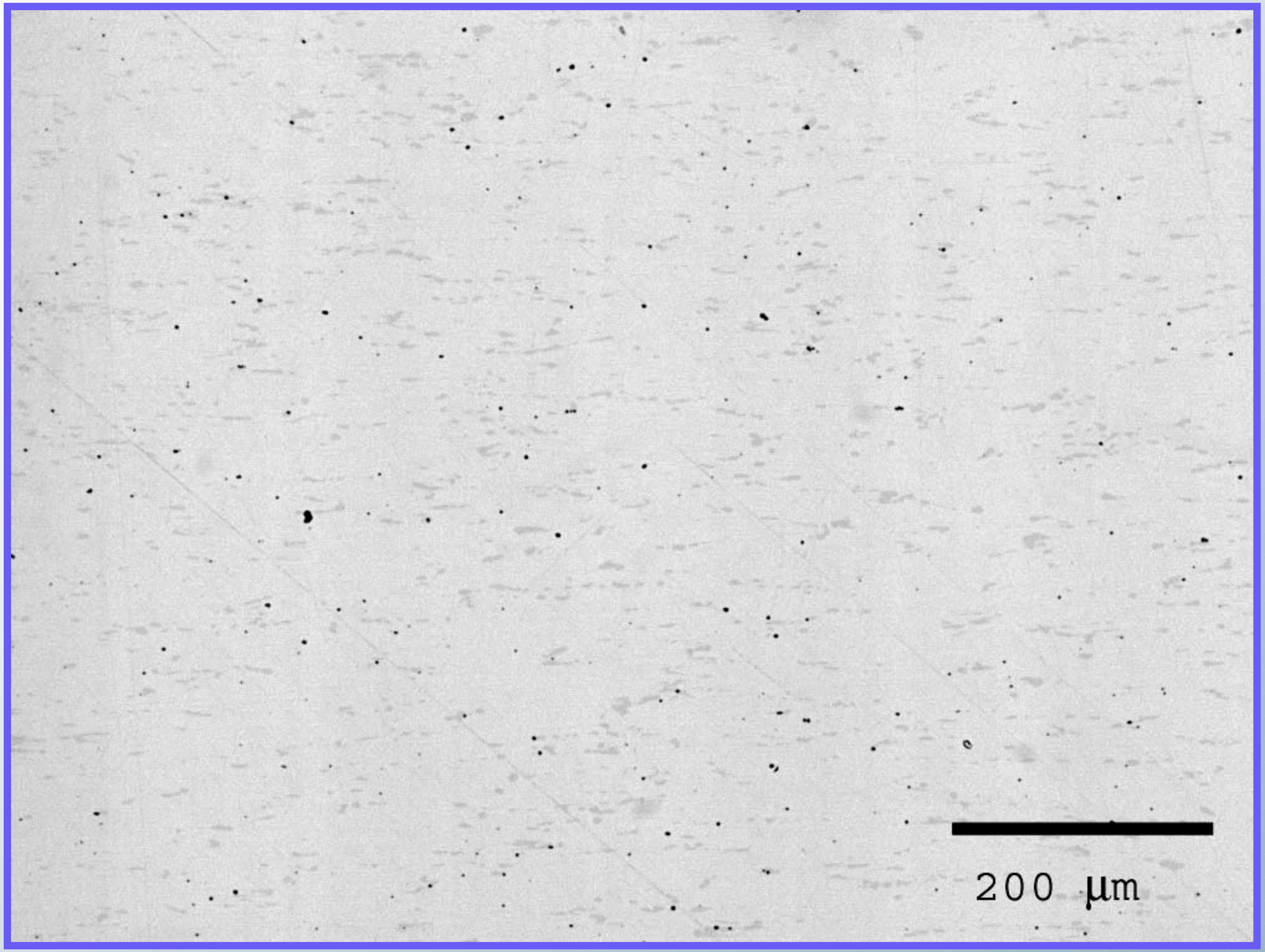


Gd Oxide (Gd_2O_3)

$(Ni,Cr)_5Gd$



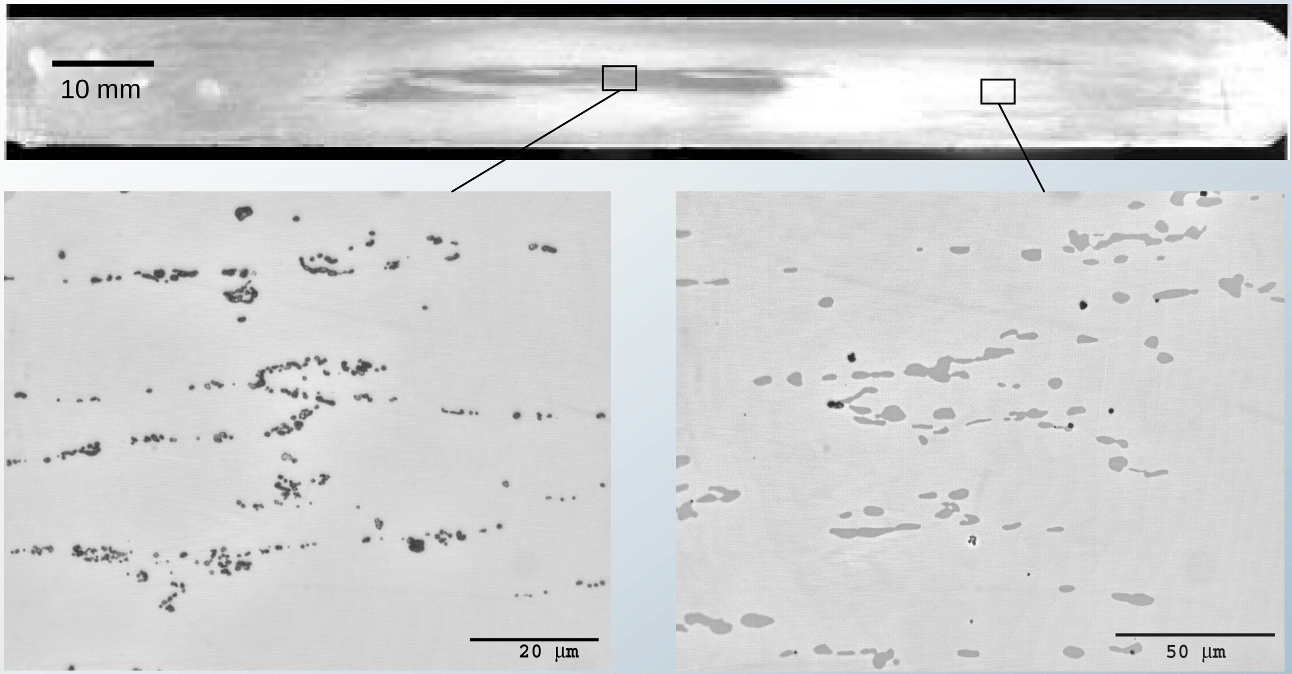
- Gadolinide identified by electron diffraction and microprobe as $(Ni,Cr)_5Gd$
- Gadolinide shape evolves during hot working, but requires additional refinement



Heat HV9810 Microstructure, gray particles are $(Ni,Cr)_5Gd$, black particles are Gd_2O_3

Plate Centerline Segregation

Transverse Cross Section of Plate



- Similar segregation encountered in conventional alloys
- Centerline of plate contains defect caused by oxide segregation in original ingot

Indicates need for secondary refining (e.g. vacuum arc remelting) and further optimization of processing

Mechanical Properties

		Tensile at 23C			*	Charpy Impact**		
Alloy	Orientation	YS (ksi)	UTS (ksi)	Elongation (%)	RA (%)	-40C Energy, ft-lb (MLE, in.)	23C	300C
HV9810	Long	54.0	118.1	41.7	44.4	25.4(.026)	24.9(.026)	33.1(.028)
HV9810	Trans	55.1	114.0	31.2	31.2	13.6(.016)	14.6(.018)	21.3(.021)
HV9814	Long	37.2	94.8	35.8	21.0	21.5(.025)	20.0(.026)	31.1(.026)
HV9814	Trans	91.1	39.2	>22.4*	12.7	11.9(.017)	11.4(.018)	18.9(.019)

*Average of three tests per condition
**Average of two tests per condition
*** All failures outside of gauge length

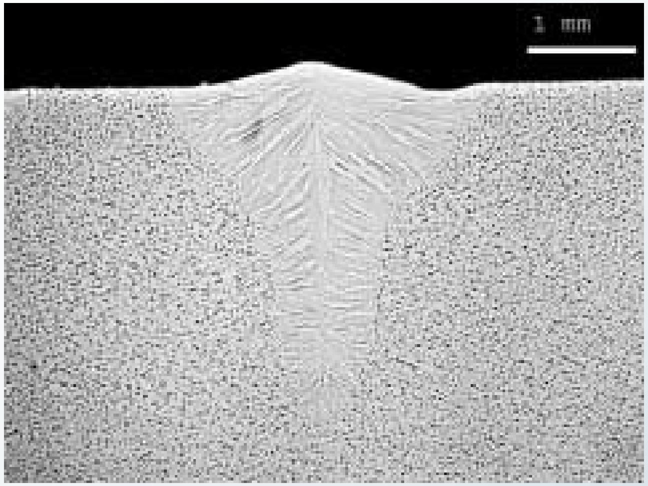
- All values are encouraging and commensurate with borated stainless steel (though at a much higher neutron absorption level
- It is expected that further optimization of processing will significantly improve mechanical properties

Alloy Chemical Analysis

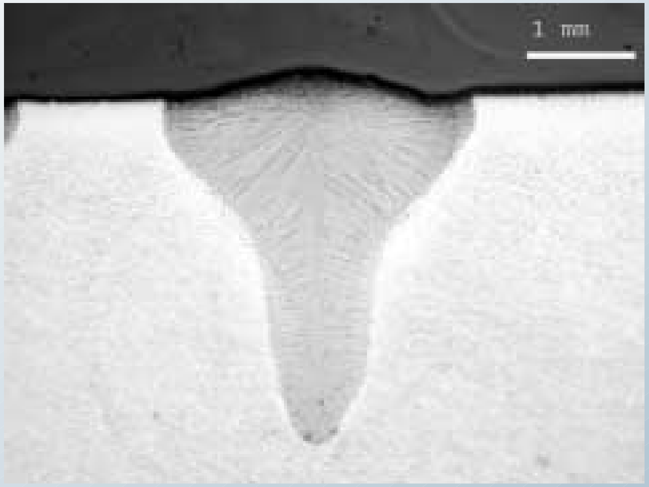
- Chemical analysis of ingots problematic
- New procedures were defined
- Round robin analyses conducted at three laboratories
- To measure chemistry variation across ingots, additional chemical analyses were performed (4 ingots x 3 locations = 12 samples)
- Results shown are comparison of results for two labs (N060455)

Element	Lab#1 (wt%)	Lab#2 (wt%)
Gd	1.5	1.62
Mo	14.13	13.99
Cr	15.52	15.49
Fe	0.3	0.059
W	0.032	0.007
Si	0.03	0.023
Mn	0.1	0.099
Co	<0.1	<0.0005
V	0.004	0.005
Al	0.065	0.029
Cu	0.006	<0.0005
Ti	0.006	0.001
C	0.021	0.0051
P	<0.01	<0.001
S	0.001	0.0004
N	0.006	0.0046
O	0.019	0.013
Ni	bal	68.6

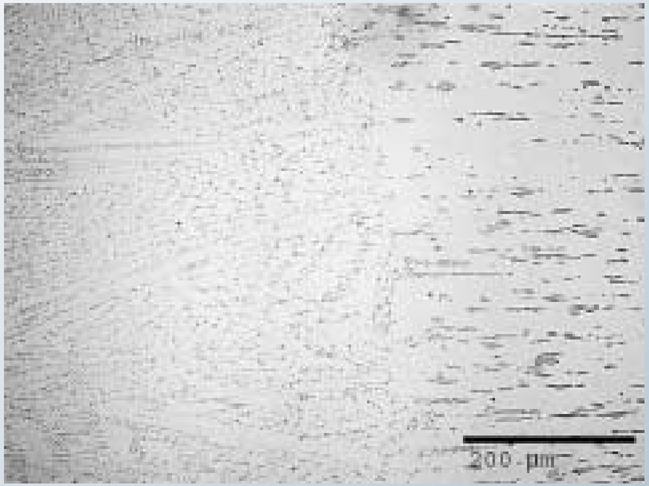
E-beam weld - unetched



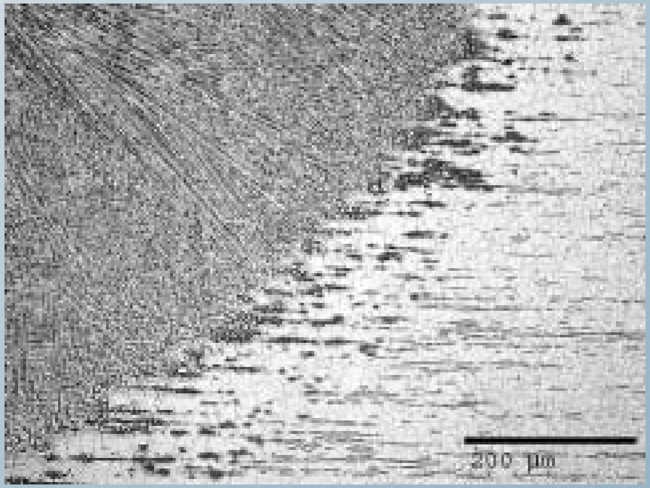
E-beam weld - etched



GTA weld fusion boundary - unetched



GTA weld fusion boundary - etched



Welding Trials, Heat HV 9810

Corrosion Test Program

Electrochemical (Cyclic Polarization)Corrosion Testing

Test Conditions

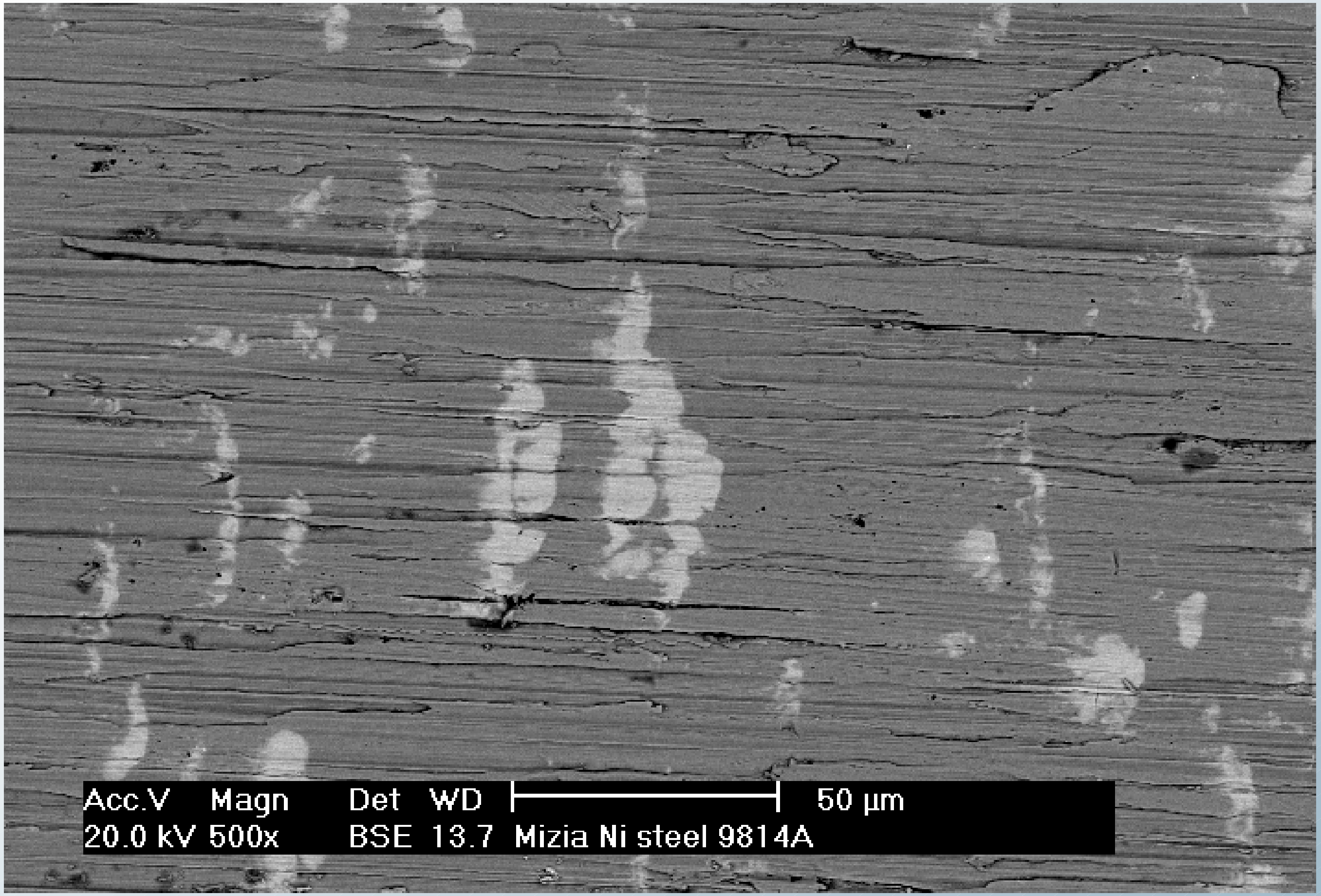
- 600 mV/hour scan rate
- 0.1 M HCl, 30ºC,
- 0.1 M HCl, 60ºC,
- 0.028 M NaCl, 30ºC,
- 0.028 M NaCl, 60ºC,
- Yucca Mountain Basic Saturated Water(BSW), 30ºC

Notes:

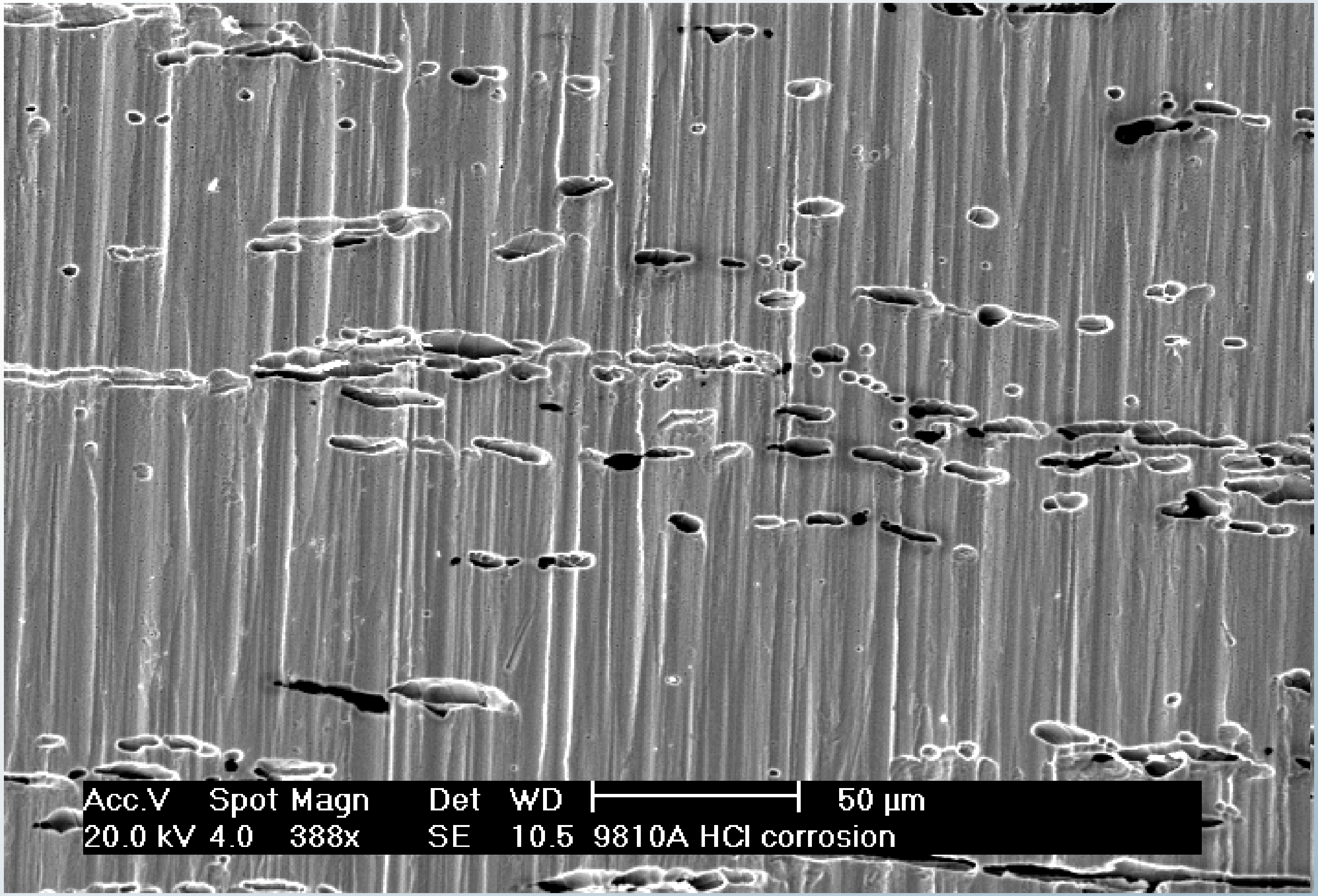
- Acidic chloride chosen for known localized corrosion initiation
- BSW is considered a bounding condition for Yucca Mountain, in-drift, water chemistry

Corrosion Test Program Results (Alloy HV 9810)

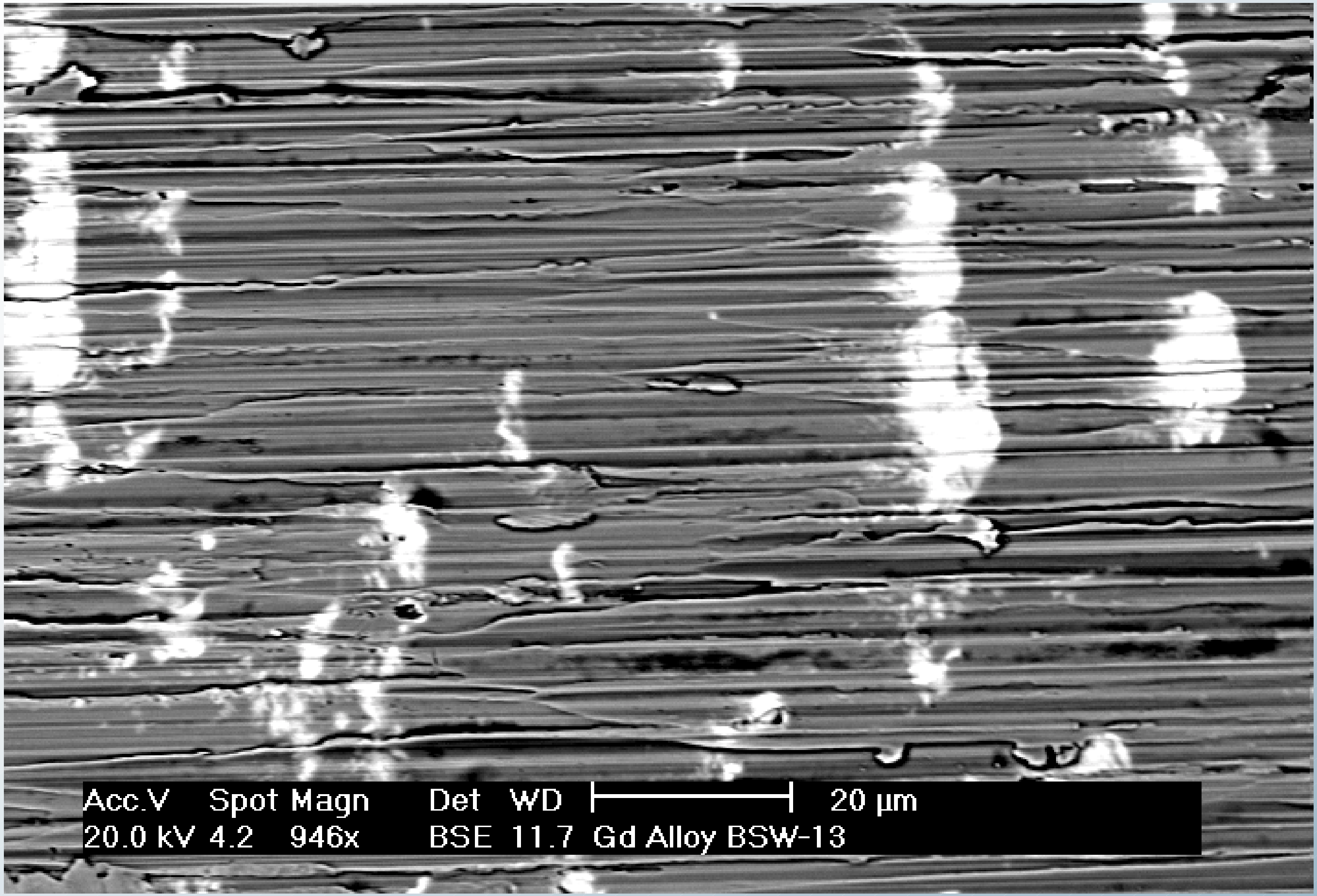
- Acidic chloride solutions will initially remove gadolinide $(Ni,Cr)_5Gd$ and Gadolinium Oxide(Gd_2O_3) that intersect the surface
  - Alloy will then repassivate
- The alloy exhibits passive behavior in BSW solution



Heat HV9810,SEM Microstructure, gray particles are $(Ni,Cr)_5Gd$, black particles are Gd_2O_3, before corrosion test



Heat HV9810,SEM Microstructure, $(Ni,Cr)_5Gd$ and Gd_2O_3 on surface removed after exposure to 0.1M HCl



Heat HV9810,SEM Microstructure, gray particles are $(Ni,Cr)_5Gd$, black particles are Gd_2O_3, present after exposure to BSW

Conclusions

- Work is successfully proceeding on the Ni-Cr-Mo-Gd alloys

– FY 01 studies of Ni-Cr-Mo-Gd alloys show acceptable high temperature forming properties, room temperature mechanical properties, weldability, and corrosion resistance

Ni-Cr-Mo-Gd Path Forward

- Evaluate & test Ni-based alloy compositions
- Manufacture master heats for code tests (mid FY 02)
- Build alloy properties data set
- Provide repository corrosion and neutronics data
- Finalize Development
  - ASTM Material Specification
  - ASME Code acceptance for welded construction
  - NRC Acceptance
  - RW approval for DOE SNF canisters